EVALUATION OF SMALL SCALE WIND TURBINES FOR PUMPING WATER

1986/87 SUMMARY REPORT

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T4-W9
87-6175

INTRODUCTION

The second year of this three-year mandate for the Lethbridge Wind Research Site commenced April 1, 1986 and will end on March 31, 1987. Funding for this year's operation was provided from three sources, including: Alberta/Canada Energy Resources Research Fund - $47,000; Federal Department of Energy Mines and Resources - $50,000; Drainage Branch of Alberta Agriculture - $48,520.00. The objectives of the testing program are primarily to:

1) evaluate the potential for wind turbines to efficiently pump water for agricultural uses; and
2) monitor, demonstrate and evaluate various types of wind pumping equipment developed, manufactured or distributed in Alberta and Canada.

In addition the site has two solar pumping systems and one electric generating turbine under test. Data from these two units will be included in the report.

ACTIVITIES - 1986/87

A) Wind Turbines

During the 1986 test period, a total of eight wind turbines were installed at the site, including seven water pumping units and the one electric generating (12.5) kW machine (Figure 1). The turbines represent a good cross-section of machines currently on the market.

WINDMILL TEST SITE

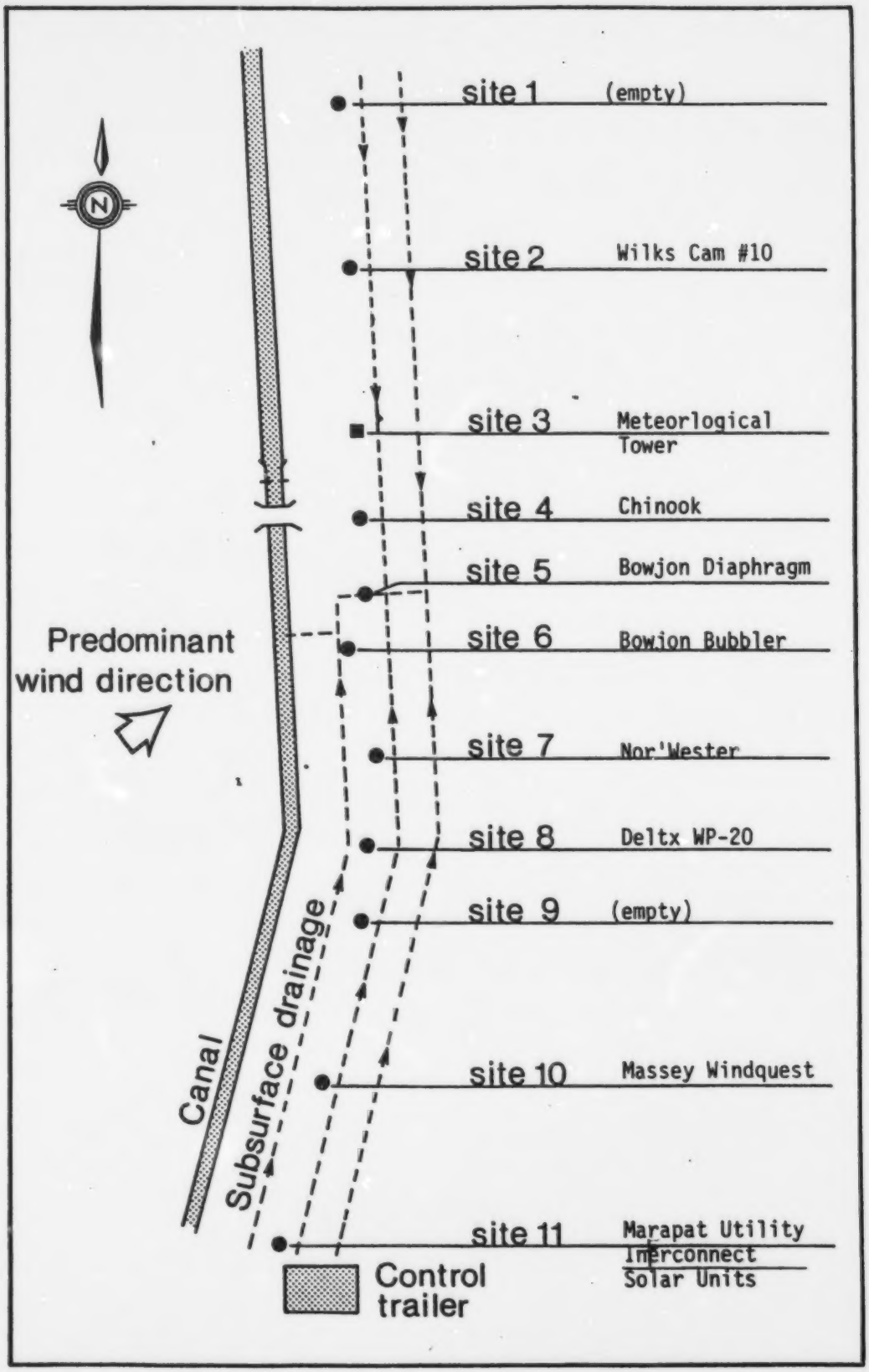


Figure 1

Model	Description	Manufacturer
Wilks Cam #10	multi-blade with piston pump	Wind Energy Unlimited, California
Chinook (7.5)	multi-blade with piston pump	Ensteel Ltd. Calgary, Alberta
Bowjon Ranger 2 units	multi-blade with air lift systems	Prairie Ditching (distributor) Lethbridge, Alberta
Maverick Windquest	X-blade with positive displacement pump	Massey Enterprises Fort MacLeod, Alberta
Deltx WP-20	delta blade with 2 piston pumps	Deltx Windpump Calgary, Alberta
Nor'Wester	two blade DC electric with battery storage	Nor'Wester Energy Calgary, Alberta
Marapat	three-blade DC electric with inversion to AC	Marapat Ltd., Stirling, Alberta

All but two of these machines were operational at various times throughout the testing season and were therefore monitored and preliminary performance curves were calculated. The two units not monitored were the WP-20 and the Nor'Wester since installation was not completed until after winterization of the site.

In addition, two solar pumping units were operational during the summer and fall. The units were manufactured by Cambrian Engineering Ltd. of Saskatoon, Saskatchewan and TPS Industries Ltd. of Toronto, Ontario. Both systems utilize photovoltaic panels hooked to DC pumps. Only the TPS Industries Ltd. unit was monitored; its performance analyses has not yet been completed.

MONITORING

A) Site Selection and Design

In order to provide a constant supply of water throughout the summer season, a site adjacent to a St. Mary River Irrigation District canal immediately east of Lethbridge was chosen as the test facility. The site, because of its location beside the canal, was affected by high water table and salinity problems due to canal seepage. A subsurface drainage system was therefore designed and installed in order to dewater the area plus provide a practical demonstration of actual field conditions in which the turbines would work.

To measure the pumping performance of the wind turbine and solar system, a closed-loop double sump system was installed. A schematic of the pumping circuit is shown in Figure 2. The unit being tested pumps water from one sump, up a predetermined distance and then into a vented standpipe. The piping used in this portion of the test circuit was sized to be consistent with actual field applications while presenting negligible dynamic head to the pump. The vented standpipe was used to separate air from the pumped water and to dampen the pulsating flows before draining through a flow metered pipe into the second sump. Each of the turbine-type flow meters were equipped with a flow rate register for local readout as well as a pickup for remote sensing. The metered pipe was designed to ensure valid flow readings. This required sloping the pipe to guarantee continuous submergence of the flow meter and sizing the pipe to decrease the turbulence in the pumped water before measurement. Also, the design ensured that the dynamic head developed in this section would not raise the water level in the standpipe to a point where it would contribute to the pumping head of the wind

turbine. The water exiting the metered pipe provided potential users with visual evidence of the wind turbine capabilities. The loop was completed when the pumped water returned to the first sump through a connecting pipe located near the base of the two sumps.

PUMPING CIRCUIT

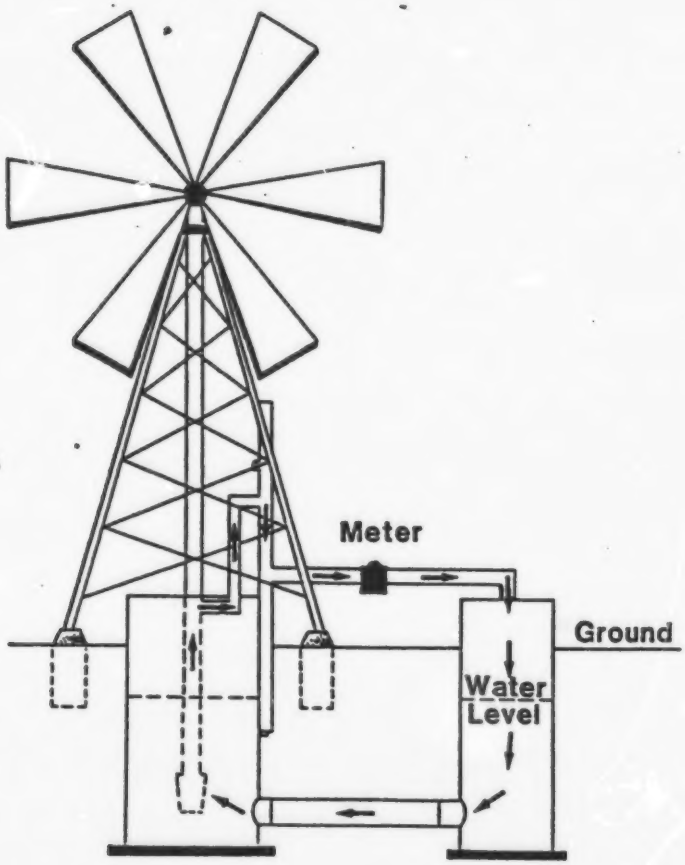


Figure 2

B) Atmospheric Sensors

A Climatronics weather monitoring package is located on a 16 m tower near the center of the site. The package consists of:

1. Four horizontal wind speed sensors mounted at 7.0, 10.0, 12.8 and 16.5 m. The locations of the sensors were chosen such that the hub height of any wind turbine tested was within one metre of the height of a wind speed sensor.
2. One wind direction sensor mounted at 16.5 m. This sensor will be used to study the effect of wind direction on the performance of the units. (Wind direction effects could include wind speed 'shading' by nearby obstructions or wind speed profile changes due to nonhomogeneous terrain).
3. One ambient temperature sensor mounted at 10.0 m and one atmospheric pressure sensor mounted at 2.0 m. These sensors were used to determine the atmospheric air density such that the performance data could be normalized to a standard air density.
4. Local displays of the wind speed and direction at the 10.0 m level for demonstration purposes.
5. Signal conditioners such that all sensor outputs could be transmitted to the data acquisition system in a consistent manner.
6. One Kipp and Zonen solar radiation sensor located at and on the same inclination as the TPS Industries Ltd. solar pumper.

C) Data Acquisition

There are many parameters which can be measured to evaluate the performance of a solar unit and a wind turbine. It was decided that the performance variables of most interest to users and manufacturers were: the volume flow rate as a function of wind speed and solar energy; the

variation of flow with pumping head and the predicted flow volumes in a given solar and wind regime. The manufacturer would also be interested in the overall performance characteristics and efficiency of his machine in order to make improvements to the design. In view of these priorities, along with budget and time constraints, it was decided to monitor pumping flow rates for each wind machine. During 1987 it is proposed that turbine rotor speed sensors will be added. More detailed performance tests will be possible for a wide variety of pumping heads upon completion of the deep well simulator. In addition, peak wind gusts were also measured at the site on the theory that turbine failure will more likely result from instantaneous high wind gusts than from sustained high average winds. Only pumping volume versus solar radiation was measured at a given head for the solar unit.

D) Monitoring System

During the 1985/86 fiscal year a considerable amount of time was spent in changing the monitoring system over from the original ISIS computer to an IBM computer system. This changeover was necessary because of the high maintenance costs associated with the ISIS unit, its low operational efficiency and small size. The ISIS computer has also been phased out by the manufacturer and parts were impossible to obtain. The changeover to the IBM system continued in the 1986/87 fiscal year and a software package has been prepared which allows for rapid, accurate monitoring of a large number of parameters.

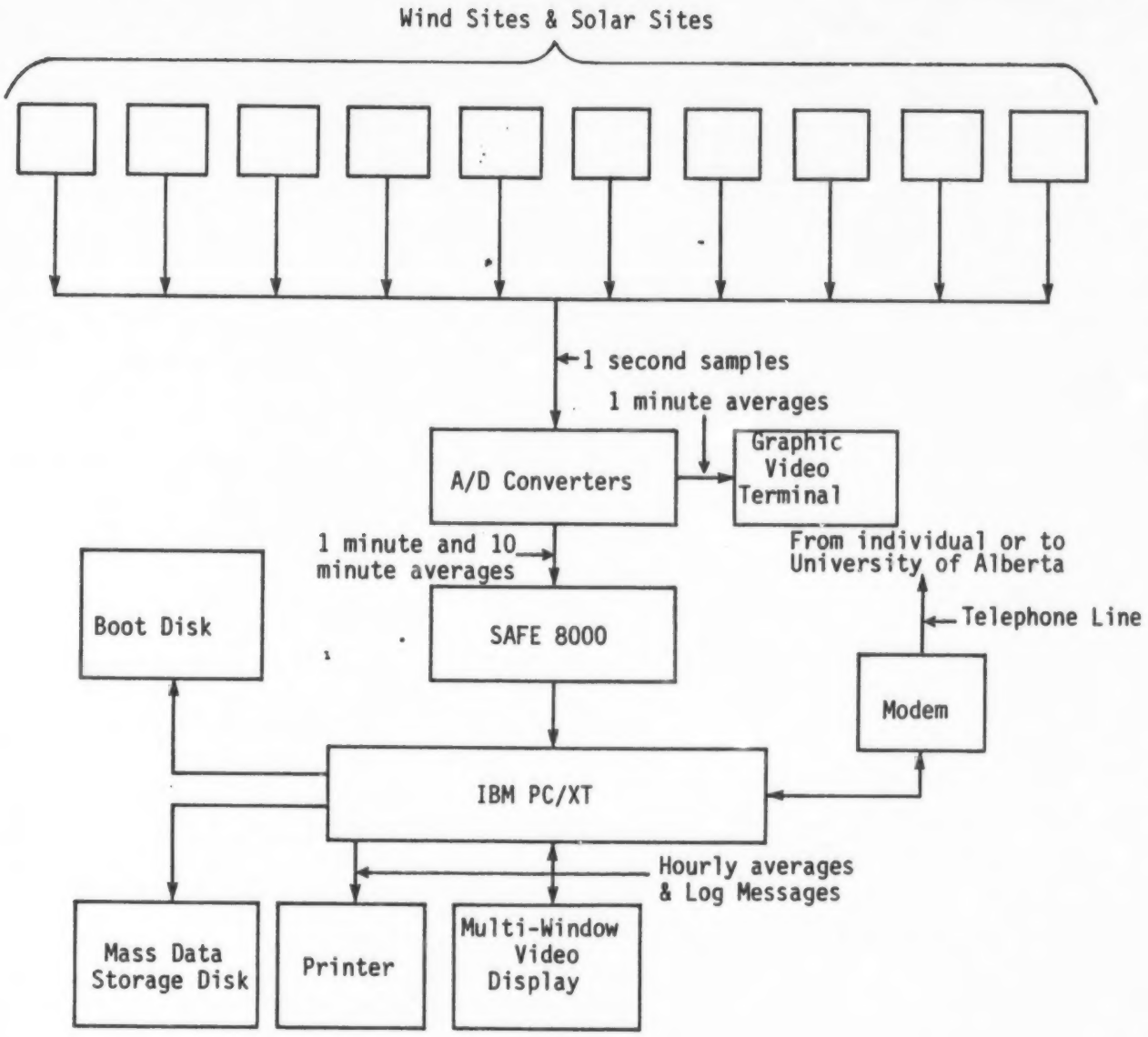
The IBM system uses a SAFE 8000 data acquisition unit for collecting and averaging field data. It is presently configured to accept up to 20 pulse inputs, 32 analog inputs, and 16 digital inputs. It can also generate four 0-10 volt analog outputs. Some of the technical capabili-

ties are described in the product brochure contained in Appendix A. The SAFE and the IBM are housed in an environmentally controlled trailer located at the south end of the test site. Its components are shown in Figure 3.

Both the SAFE and IBM system's hardware and software have been designed to allow for simple expansion. The IBM uses a UNIX based operating system such that it can operate in a multiuser/multitasking environment. As mentioned previously, a software package (written in C) was prepared in 1986/87 to facilitate the data collection, processing and transmission.

The on-site processing includes producing hourly averages of each sensor input and automatically producing daily summary reports of these values. The ten minute average data is stored on the hard disk (providing thirty days of backup storage), and once per day is transmitted via DATAPAC to the University of Alberta mainframe computer. The software and database is also designed such that an individual can dial into the system and determine the present operating status of each machine. The individual, through this menu driven software may also obtain a copy of any portion of the stored data or the hourly summaries for direct use with a graphics package such as Lotus 1-2-3. The operating system is also configured such that password protection allows only authorized personnel from performing modifications to the IBM or SAFE software. Because of the UNIX based operating system, all these tasks can be performed without interrupting the data monitoring process.

The monitoring system worked well throughout the summer and fall of 1986. In December, however, problems with the data acquisition system occurred when the Marapat electric turbine was being monitored.



DATA ACQUISITION SYSTEM

Figure 3

The system has been repaired, but the cause of the problem was never determined for certain. It is believed that the DC power supply system could not operate properly when it used the power generated by the Marapat unit. During these periods, the synchronization of the voltage and current cycles (power factor) was extremely poor and as such could have had the effect of causing rapid voltage fluctuations from the DC rectifier.

E) Monitoring and Analysis Procedure for the Development of Performance Curves

The monitoring procedures at the test site closely follow the Canadian Standards Association Performance Testing Standard (F417). Analog signals (weather monitoring package, current and voltage measurements) were sampled each second and averaged every ten minutes. Pulse signals (flow meters and future rotor speed sensors) were transmitted to accumulators which were read and reset every ten minutes. These ten-minute records were temporarily stored in a data base on a hard disk at the site. Each day at 1730 MST, the data records for the previous twenty-four hours were automatically transferred to the University of Alberta mainframe.

At the end of the test season, the data which had been received and stored at the University of Alberta were processed into performance curves for each unit. The analysis was performed using both a statistical package known as the Michigan Interactive Data Analysis System (MIDAS) on the mainframe computer (to eliminate data recorded during inoperative periods) and Lotus 1-2-3 on IBM personal computer (to visually fit a curve through the remaining data).

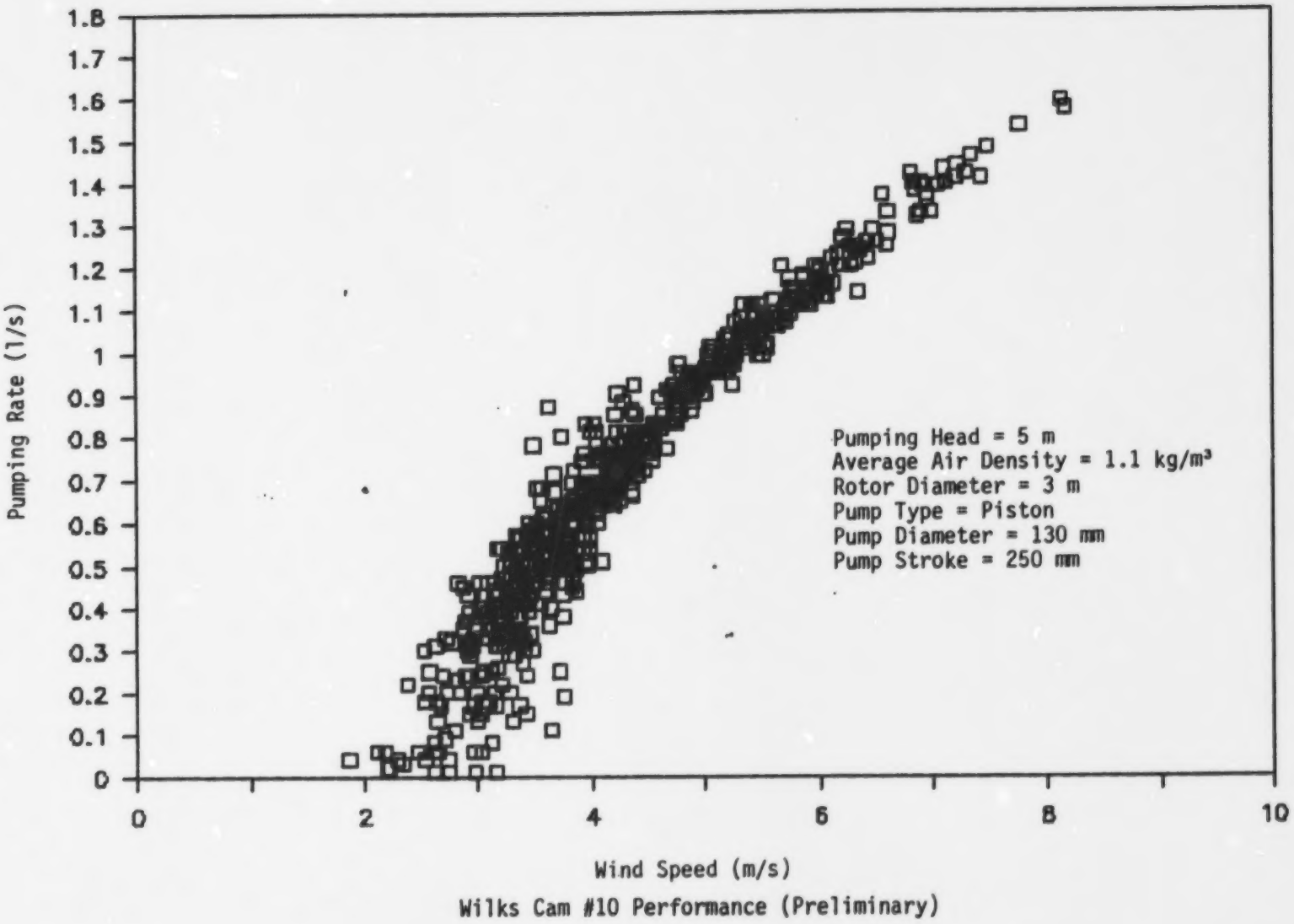
RESULTS

Preliminary performance curves were calculated and prepared for five of the seven wind turbines on the site. Three of the units were modified mid-season, and as such two performance curves were produced to illustrate the improvements made. Prior to each performance curve the data used for their preparation (or just the post-improvement data in the case of the two-curve units) has been presented as a scatter graph. Additional data analysis is being carried out to finalize the performance curves and calculate expected pumping yields for each of the mills at various sites in Alberta (which do not conform to a Rayleigh distribution) and for various mean monthly wind speeds based on a Rayleigh distribution. Also, the analysis for the TPS Industries Ltd. solar pumper is expected to be completed shortly.

The operational performance of each of the mills is summarized as follows:

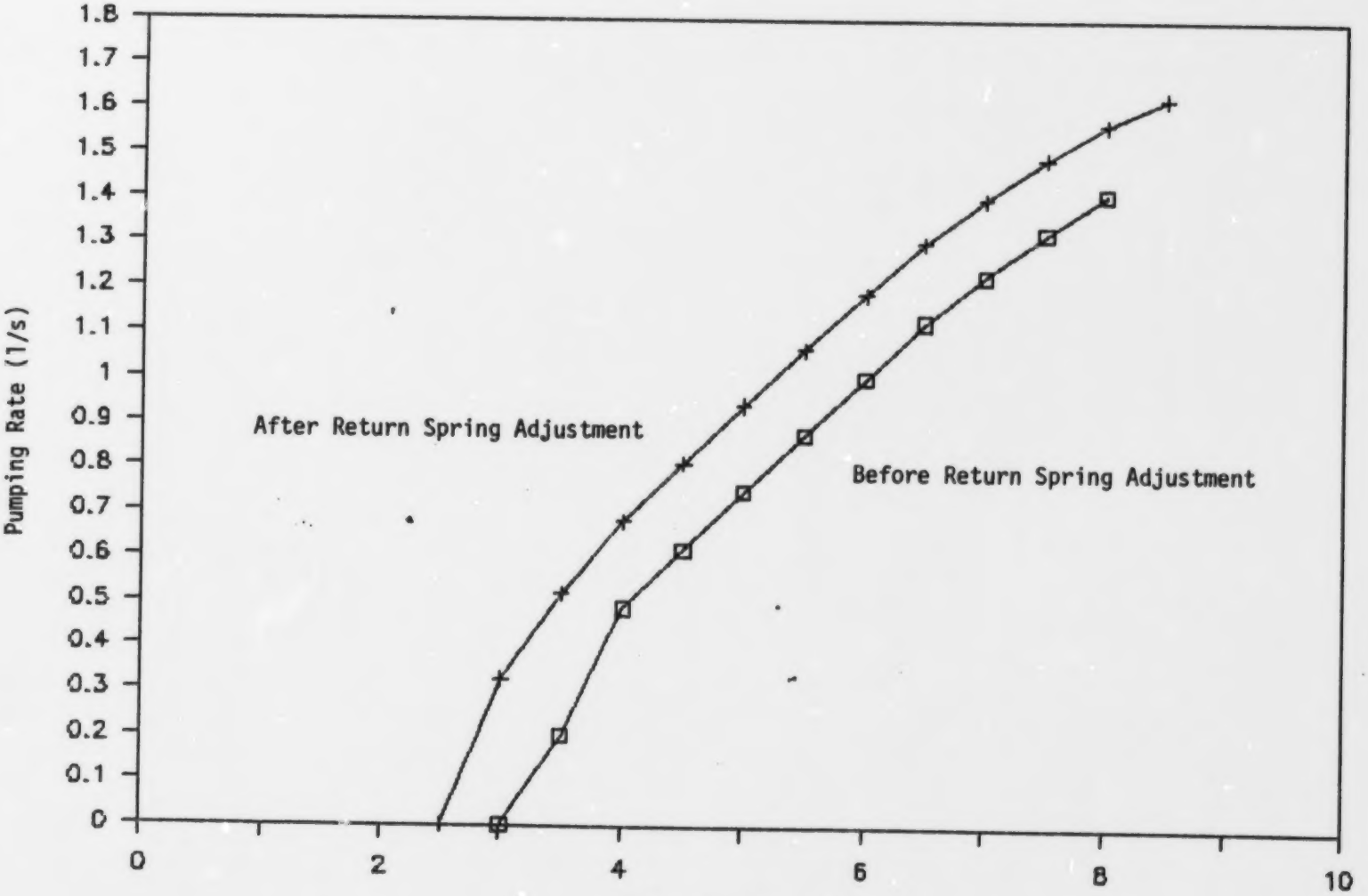
Wilks Cam - (Figures 4 & 5) Installed in late summer and operated nearly continuously until freeze-up. The unit was modified in mid-October by increasing the force developed by the springs which return the pump rod down into the well. This modification is shown to significantly improve the performance of the system throughout is operating range. Insufficient data was gathered to continue both curves above 9 m/s. Additional testing in 1987 will be required to complete the latest curve.

Chinook - (Figures 6 & 7) Installed winter of 1985 and has only operated intermittently since then, due to problems with the PVC pump system. The unit operated continuously during



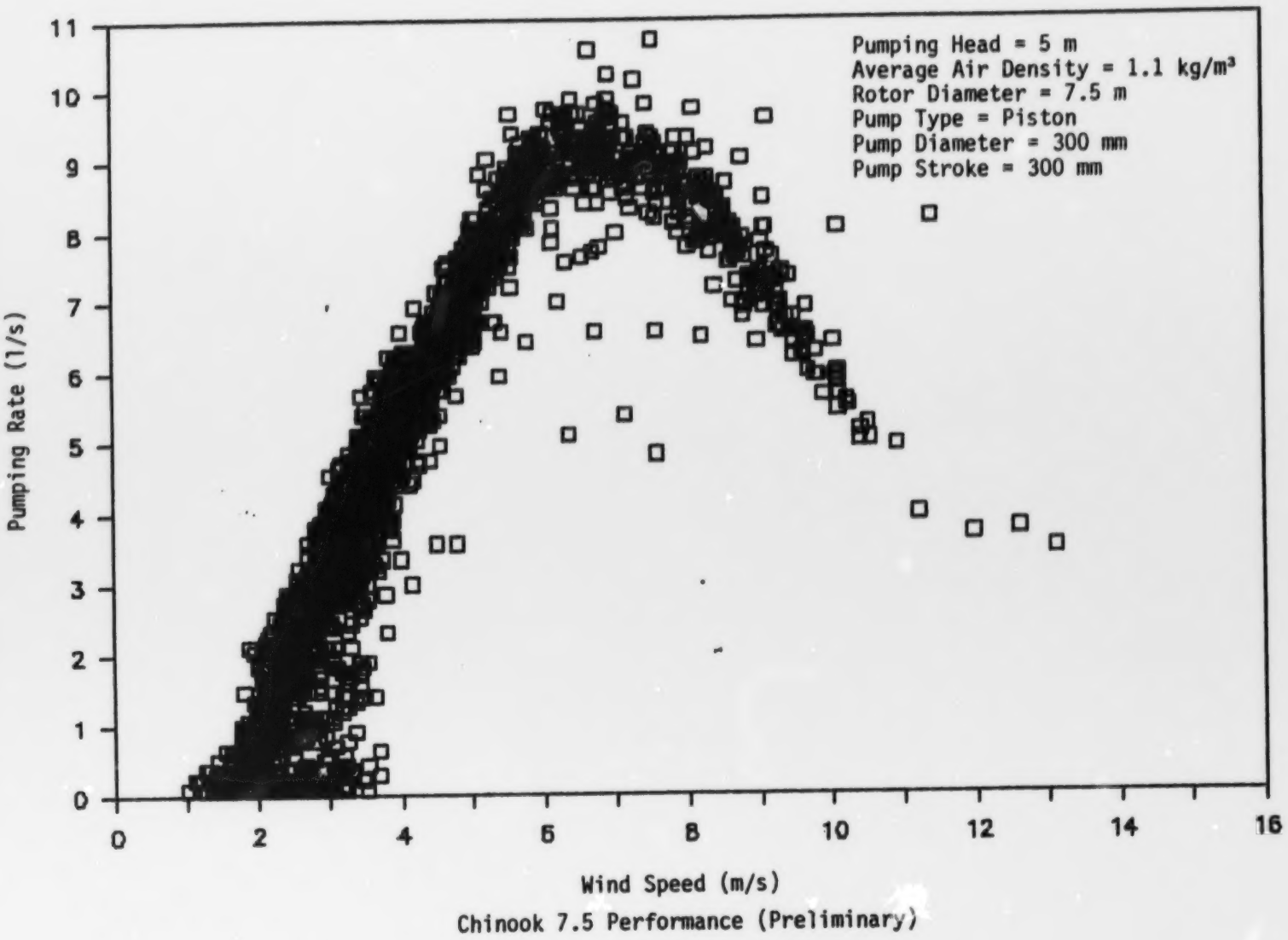
Wilks Cam #10 Performance (Preliminary)

Figure 4



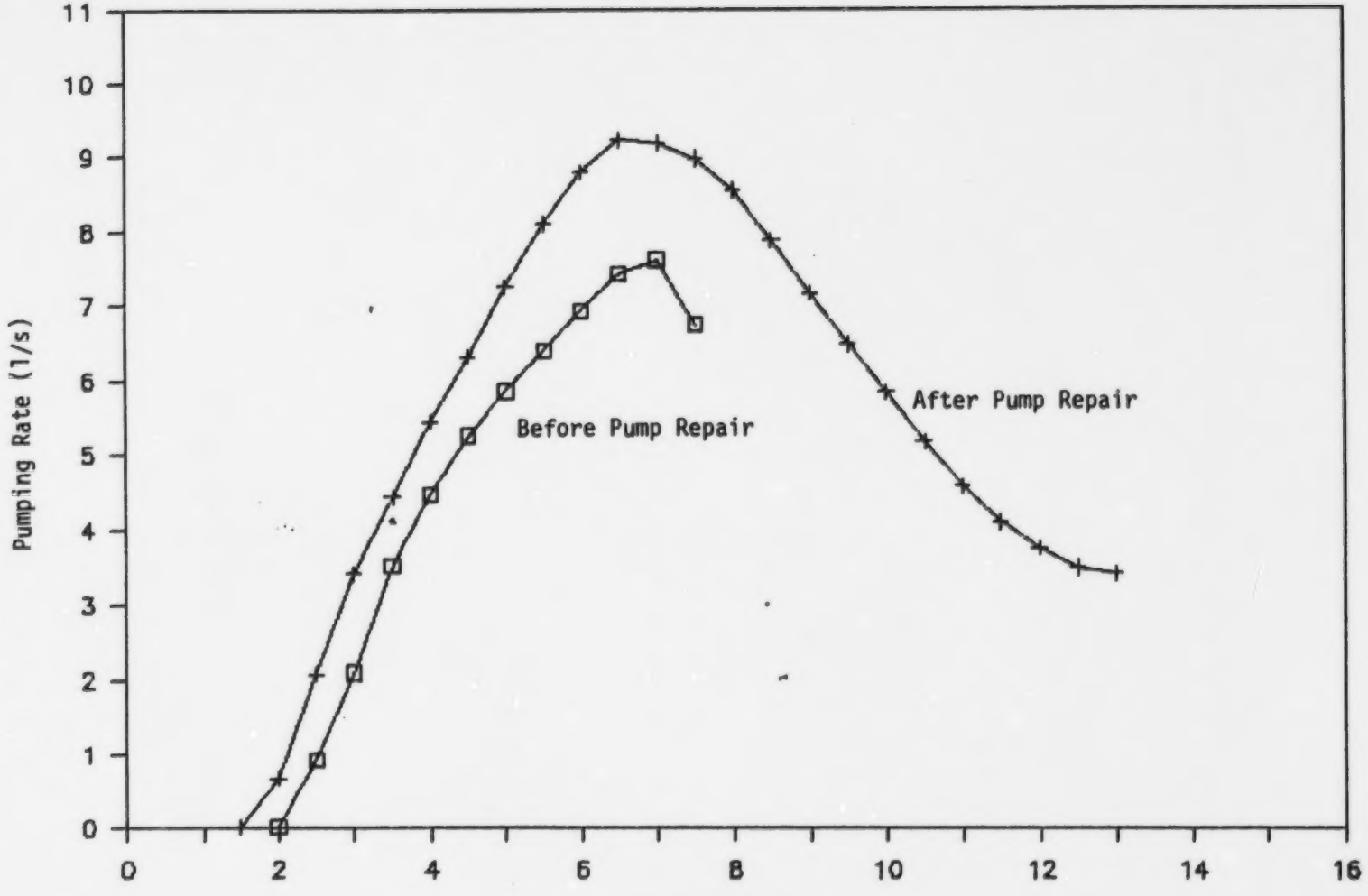
Wilks Cam #10 Performance (Preliminary)

Figure 5



Chinook 7.5 Performance (Preliminary)

Figure 6



Chinook 7.5 Performance (Preliminary)

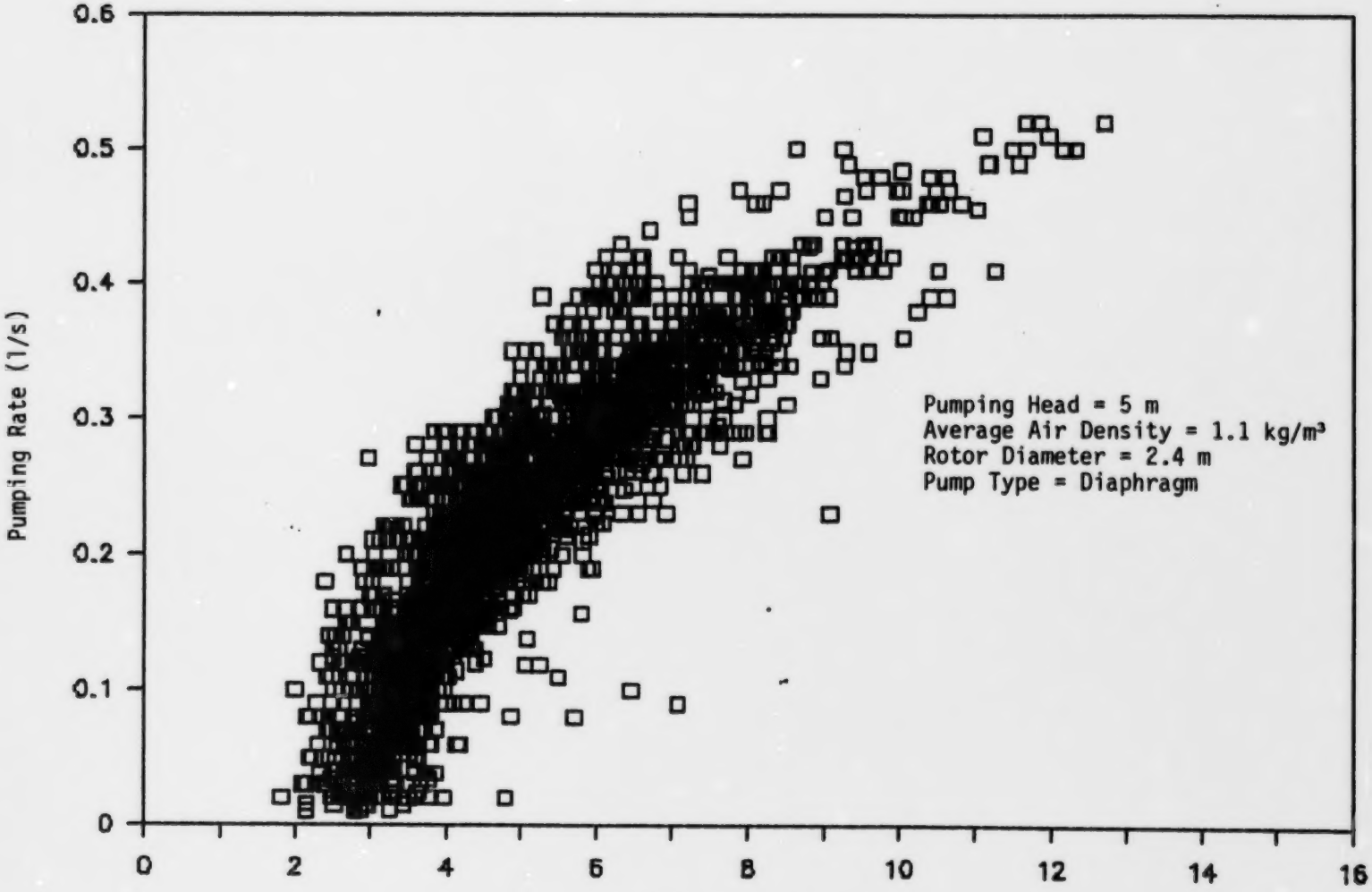
Figure 7

October of 1986, after the pump had been repaired. It can be seen that the peak performance after the pump repair increased by approximately 20%. This unit possessed the lowest cut-in wind speed (1.5 m/s) of all machines tested during 1986.

Bowjon Diaphragm - (Figures 8 & 9) Installed during the summer of 1985 and operated nearly continuously throughout the 1986 test season. This unit is configured to drive a diaphragm pump by an air compressor. It lost its rotor assembly in late fall of 1986. Replacement is expected by spring of 1987. Overall performance of this unit has not been as good as the previous Bowjon airlift system which used the same rotor and compressor.

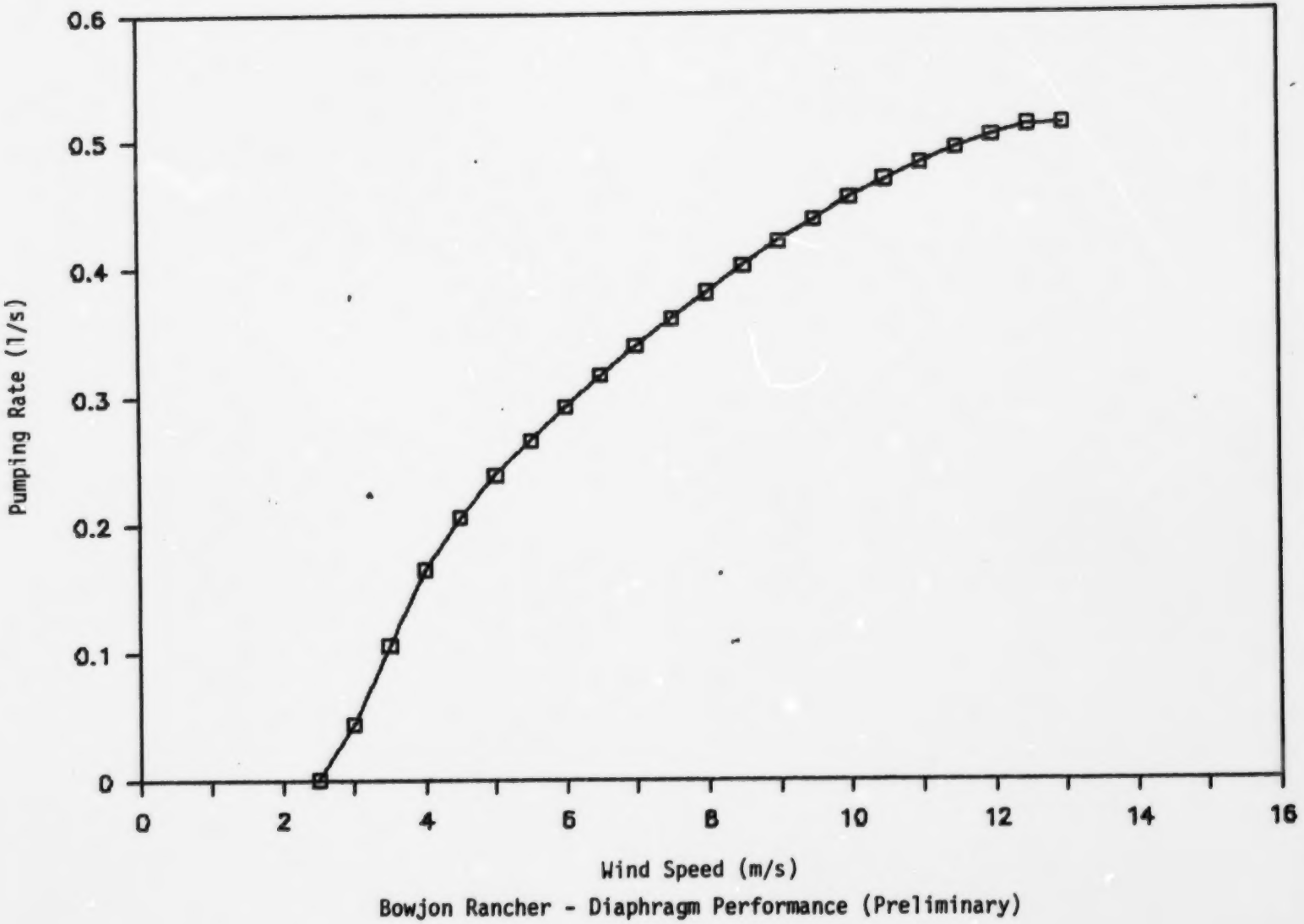
Bowjon Bubbler - (Figures 10 & 11) As with the Bowjon 1 this unit was installed during the summer of 1985 and operated nearly continuously throughout the 1986 test season. This unit is similar to the previously tested Bowjon airlift unit, but the compressor has been modified. After solving initial problems with the compressor, it was still not able to equal the performance of the previous unit. The 4.5 m/s cut-in wind speed was the highest of all machines tested during 1986.

Maverick Windquest - (Figures 12 & 13) Installed during the summer of 1986 and operated somewhat erratically until late fall when the drive cable broke. The unit also displayed problems with balancing of the swivel tower resulting in poor wind tracking and



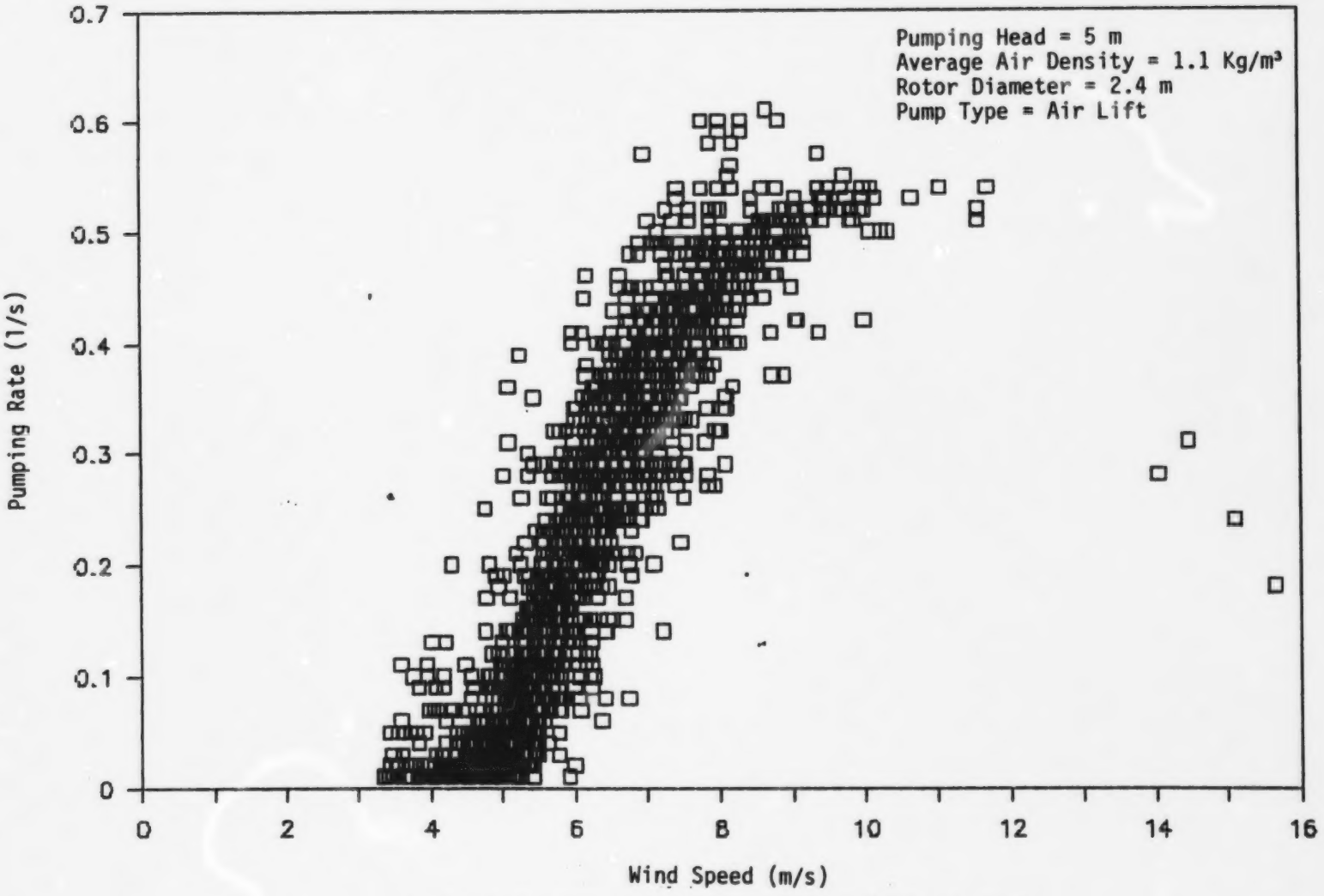
Bowjon Rancher - Diaphragm Performance (Preliminary)

Figure 8



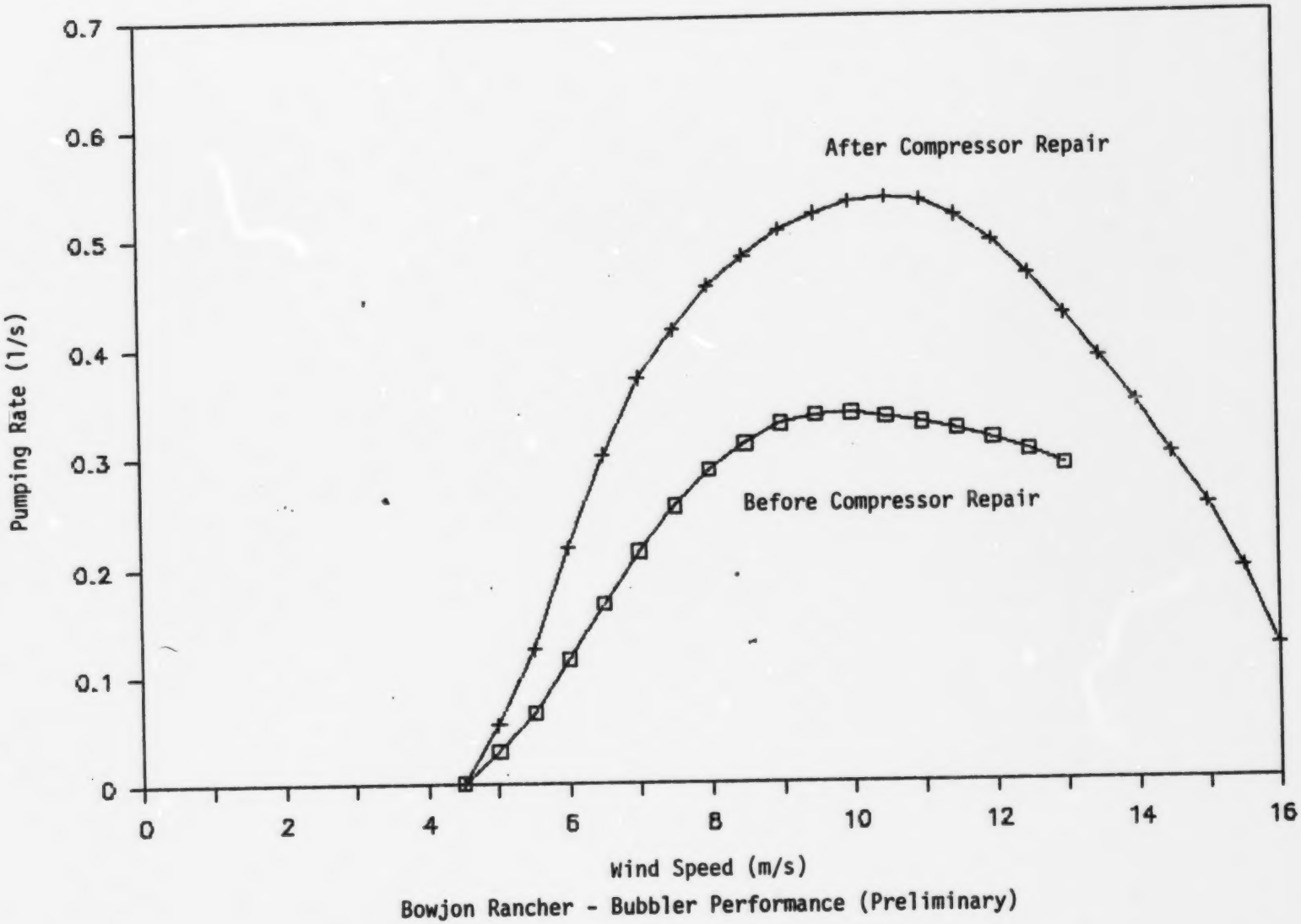
Bowjon Rancher - Diaphragm Performance (Preliminary)

Figure 9



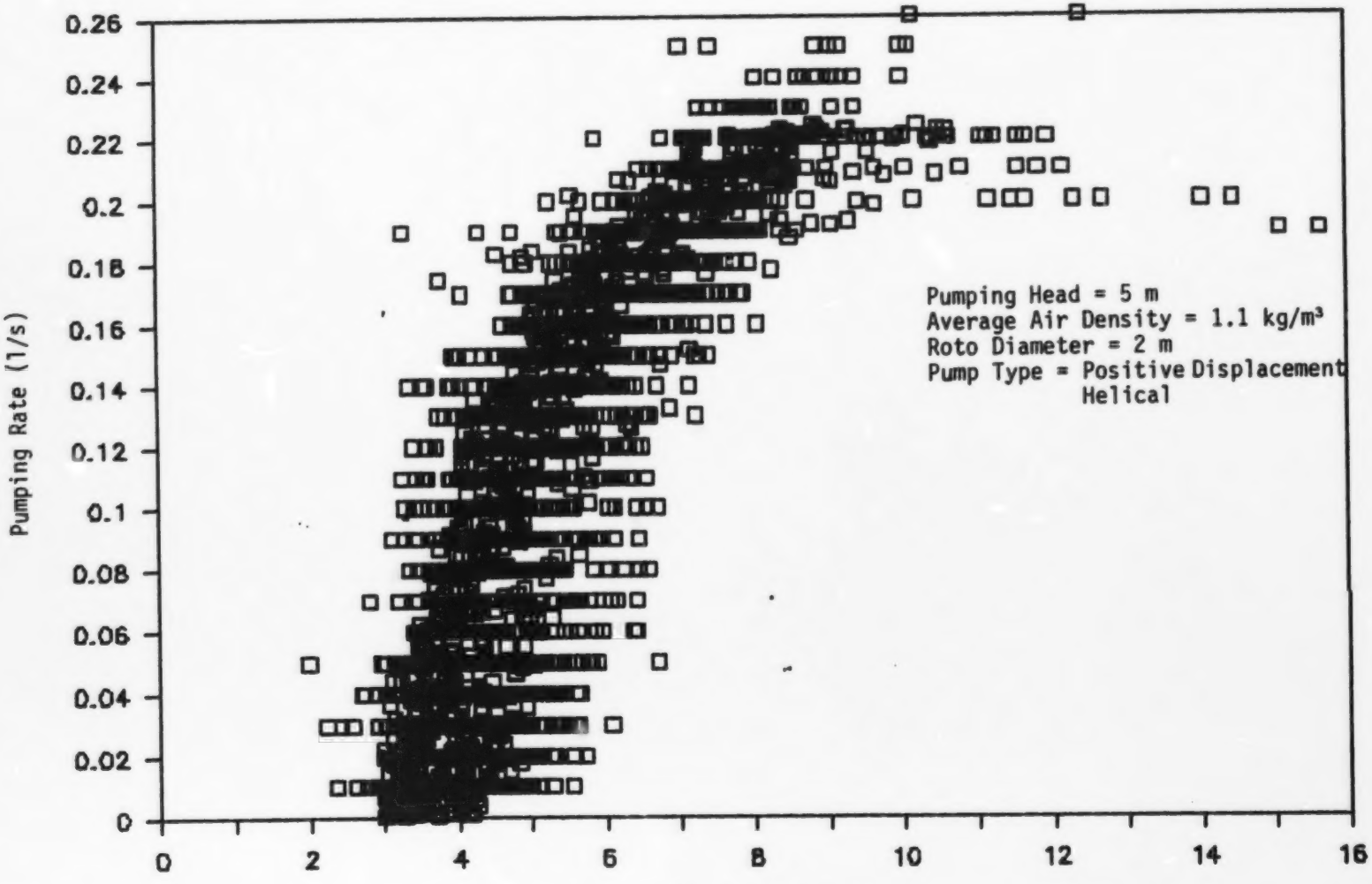
Bowjon Rancher - Bubbler Performance (Preliminary)

Figure 10



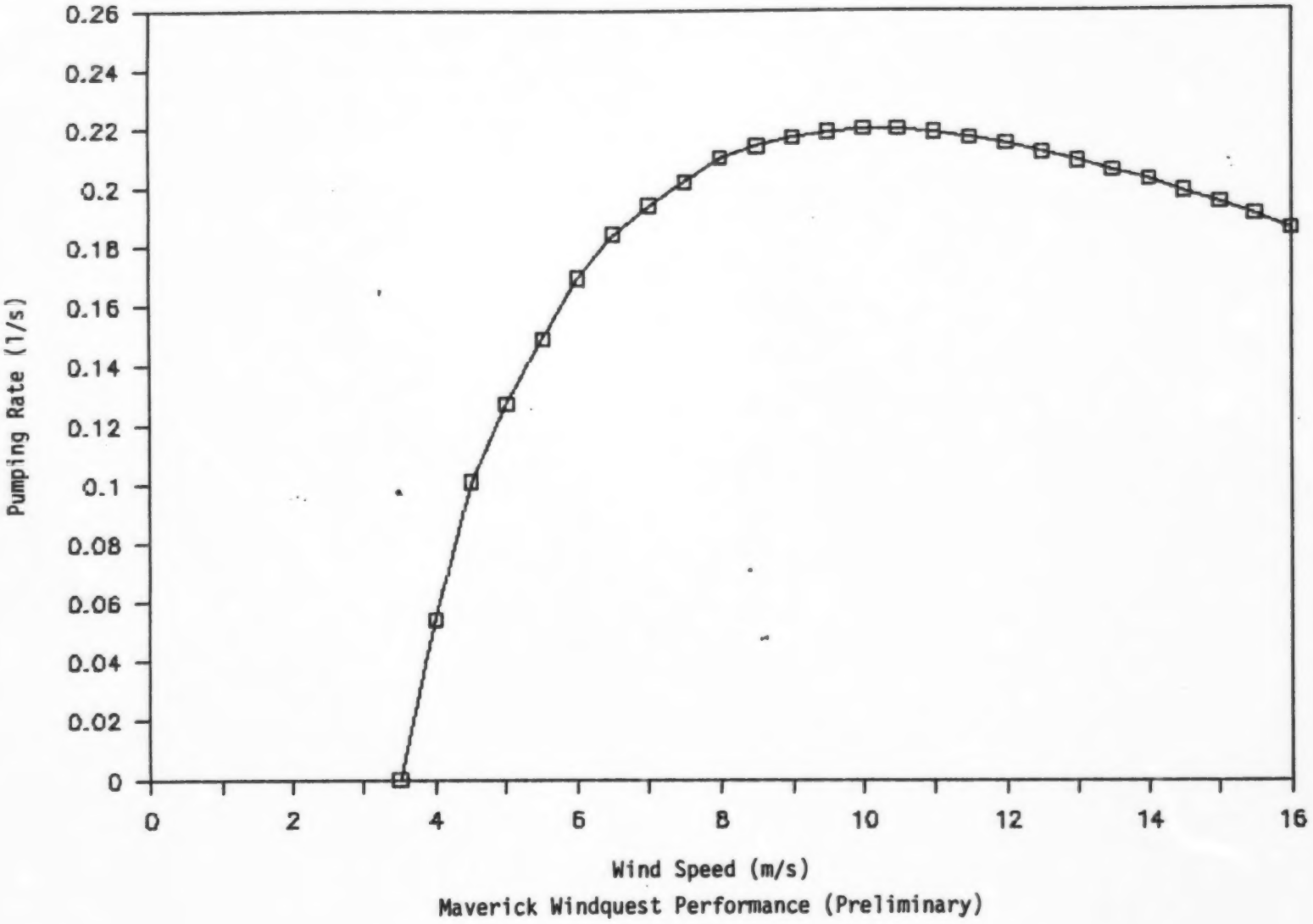
Bowjon Rancher - Bubbler Performance (Preliminary)

Figure 11



Maverick Windquest Performance (Preliminary)

Figure 12



Maverick Windquest Performance (Preliminary)

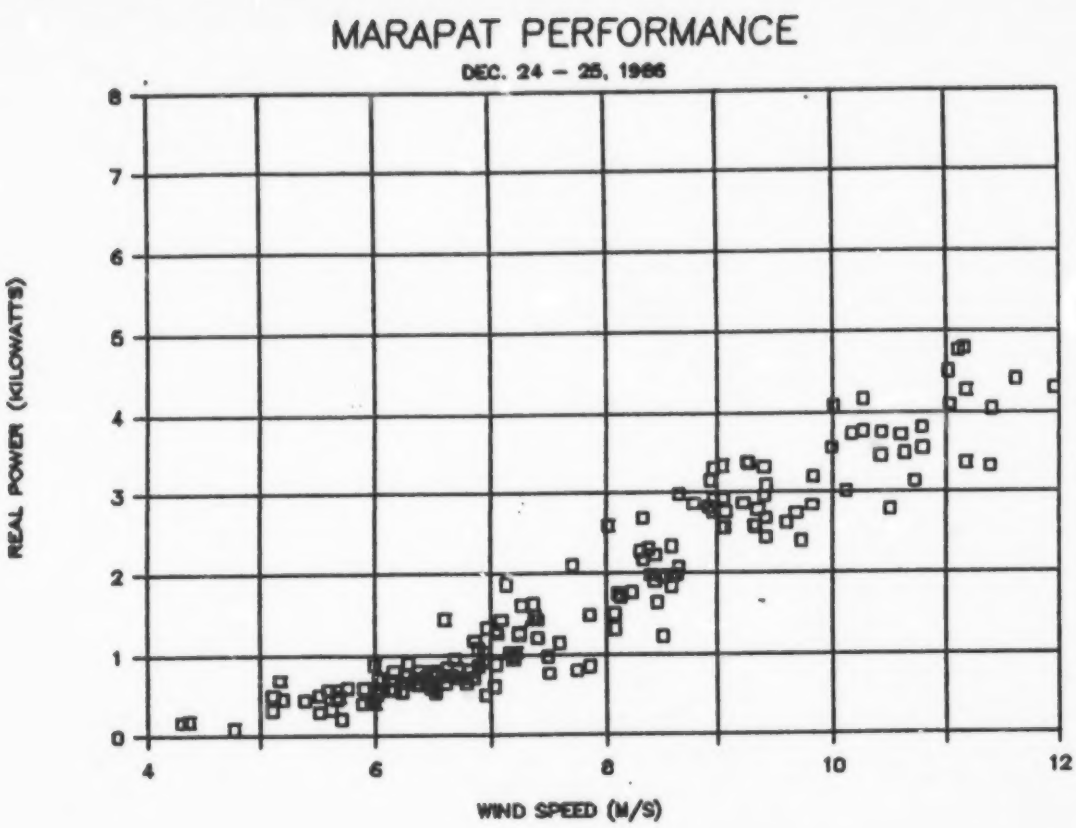
Figure 13

inconsistent performance. The unit has been dismantled and returned to the manufacturer's shop for repair and redesign.

WP-20 - Originally installed in winter of 1985 using a mechanical drive system. After six days of operation the mechanical drive broke and no further testing was carried out until the drive was replaced with a hydraulic system in late fall of 1986. Simulated testing was carried out by measuring strokes of the hydraulic ram for one to two weeks. Problems with the ram has halted further testing until the spring. The switch from mechanical to hydraulic drive appears, however, to have excellent potential for this unit.

Nor'Wester - Installation was initiated in the summer of 1986 but is not yet complete. Testing of this machine is expected to commence by May of 1987.

Marapat (12.5 Kw) - Installation of this unit was initially completed in the fall of 1985. After twenty-four hours of operation this machine fell down due to high winds and inadequate support cable strength and anchors. Installation of a replacement unit took place in the spring of 1986 but operation of the unit did not begin until December 17, 1986 because of various problems with the alternator and blade systems. On December 25, 1986 the machine lost two of its three blades. Performance data (Figure 14) shows the machine has serious problems with quality and quantity of power output. The manufacturer is currently trying to determine what these problems are.


MARAPAT PERFORMANCE
DEC. 24 – 25, 1986
REAL POWER (KILOWATTS)
WIND SPEED (M/S)
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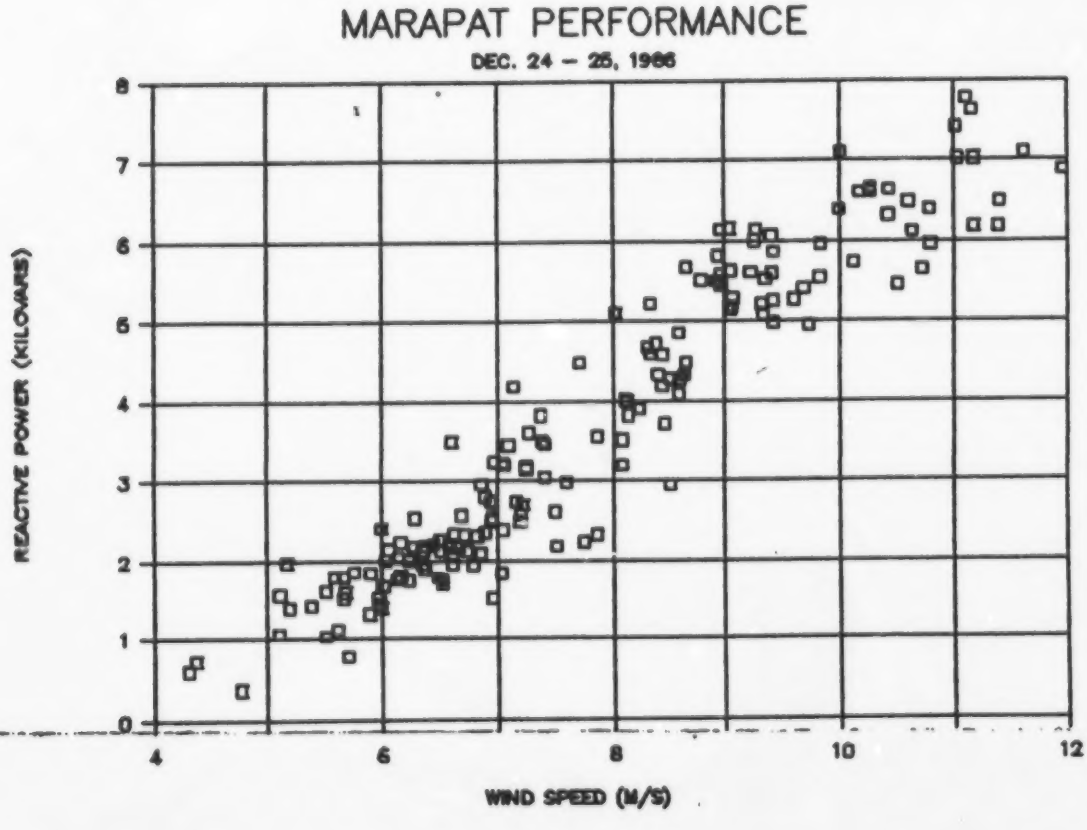
10
12


MARAPAT PERFORMANCE
DEC. 24 – 25, 1986
REACTIVE POWER (KILOVARS)
WIND SPEED (M/S)
0
1
2
3
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7
8
4
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8
10
12

Figure 14

Cambrian & TPS Solar - The Cambrian has been operational at the site for approximately three years while the TPS unit was installed during the summer of 1986. Both systems have operated continuously since their installation with essentially zero down time. They are by far the most maintenance free systems on the site.

A common problem with almost all wind turbine manufacturers is finding or developing a suitable pump which will handle relatively large volumes of water at shallow lifts. Overall system efficiency and mechanical integrity often suffers because of a poor match between the pump and the turbine system. Additional research on testing various pumping systems in relation to wind turbine performance is recommended.

STAFF

Two consultants are contracted to assist with the overall operation and management of the Lethbridge Wind Research Site. Mr. D. Baker, President of DRB Engineering Consultants Ltd. (Calgary) is responsible for data collection and analysis, computer systems operation and maintenance plus inputs to the various reports. Mr. E. Jensen, President of Jensen Engineering Ltd. (Olds), is responsible for site design, liaison with wind turbine and solar manufacturers and data analysis related to economics and practical application of collected data.

In addition, an engineer was hired to assist with the operation and maintenance of the Research Site throughout the summer period. Mr. W. Ulmer of the Drainage Branch worked closely with the engineer in carrying out the day-to-day operations, including installation of sensor equipment, anemometers, etc. A significant portion of time was spent in

overhauling the leaking sump systems which store and allow circulation of the water which is pumped by each of the turbines and solar systems. This problem was corrected and much more reliable data was therefore collected throughout the summer. Project management will continue to be carried out by Mr. B. Paterson, Head of the Drainage Branch of Alberta Agriculture.

BUDGET

The total budget required to operate the Lethbridge Wind Research Site for 1986/87 was $145,520. This included: $50,000 from the Department of Energy Mines & Resources; $47,000 from the Alberta/Canada Energy Resources Research Fund, which is administered by the Alberta Department of Energy & Natural Resources; and $48,520 from the Drainage Branch of Alberta Agriculture.

CONCLUSIONS

The monitoring and testing program being carried out at the Lethbridge Wind Research Site has resulted in continued and even increased interest by manufacturers and government representatives throughout North America and Europe. At least one of the Alberta manufacturers with a machine on the site has been offered the chance to demonstrate their turbine for possible sales in the Caribbean. Export potential for some of the other units on the site is also a real possibility. However, the independent testing provided at the site appears to be an important prerequisite for this market.

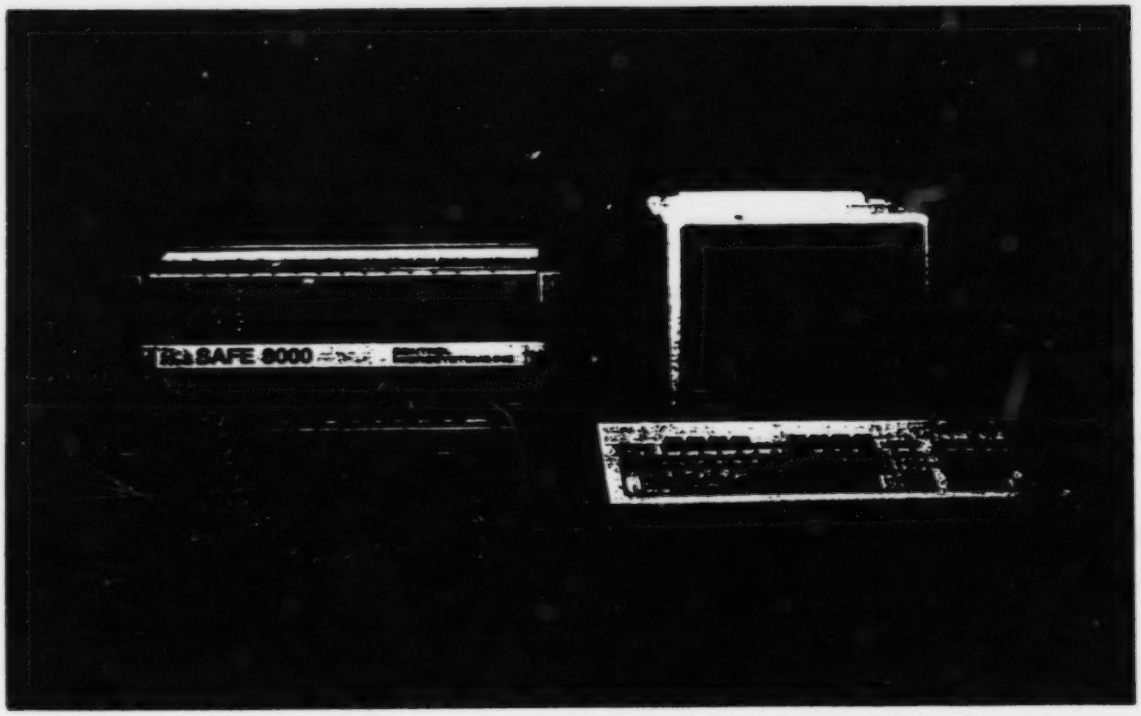
There is interest by at least three additional manufacturers to install machines on the site for testing during the summer of 1987. The site is only capable of testing one to two additional units without

expanding and we will therefore accept the first two units which are capable of being monitored by May of 1987.

APPENDIX A

NEW

CONTROL MICROSYSTEMS INC.



SAFE 8000

BASIC LANGUAGE I/O SYSTEM

REMOTE TERMINAL UNIT

INTELLIGENT PROGRAMMABLE I/O SYSTEM

STAND ALONE PROCESS COMPUTER

INTERTECHNOLOGY INC
1 SCARSDALE ROAD DON MILLS ONTARIO M3B 2R2
MONTREAL OTTAWA WINNIPEG CALGARY VANCOUVER

GENERAL

The SAFE 8000 Stand Alone Front End Computer System is a complete, cost effective solution to a broad range of industrial control and data acquisition problems. The SAFE 8000 replaces data loggers, programmable controllers, setpoint controllers and many other dedicated devices while offering greater flexibility and broader functionality.

The SAFE 8000 is designed to function as either an extended BASIC programmable front end for personal or minicomputers, or as a stand alone process control system. The SAFE 8000 provides 64 PID controllers, 'ladder-diagram' type digital logic, 128 analog and 2048 digital I/O signals, multitasking, 26 priority interrupts and 128 software timers.

The SAFE 8000 communicates via two serial ports with virtually any host computer, terminal, printer, modem, programmable controller or peripheral device which uses RS-232 or RS-422.

APPLICATIONS

Applications of the SAFE 8000 include: industrial control and data acquisition, personal computer control systems, laboratory automation, energy management, pollution monitoring, machine control, remote terminal monitoring, alarm annunciation, and signal multiplexing to name a few.

PROGRAMMING LANGUAGE

The SAFE 8000 is programmable in SAFE BASIC, a full implementation of BASIC which includes a large number of process control extensions. Features include 9 digit floating-point arithmetic, 26 priority interrupts, multitasking, error trapping, multi-statement lines, 128 software timers and PID contollers.

SAFE BASIC COMMANDS: ABS, AND, ASC, ATN, AUTO, CHANGE, CHR$, CLR, CONT, COS, DATA, DEF, DELETE, DIM, EOR, END, ERROR, EXP, FIND, FOR/NEXT/STEP, FRE, GET, GOTO, GOSUB, IF, INPUT, LEFT$, LEN, LET, LINPUT, LIST, LOG, MID$, NEW, NOT, ON GOTO, ON GOSUB, OPEN, OR, PACK, PEEK, POKE, PRINT, READ, REM, RENUM, RESTORE, RESUME, RIGHT$, RUN, SGN, SIN, SQR, STOP, STR$, SWAP, SYS, TAN, TRACE, UNTIL/REPEAT, VAL, WHILE/REPEAT

PROCESS CONTROL AND EXTENTION COMMANDS: AIN, AOUT, BAND, BEOR, BOR, CVBCD, CVBIN, DIAGNOSTICS, DIN, DOUT, IF OFF, IF ON, INTERVAL, LOGIC, ON IRQ GOSUB, ON COM GOSUB, PID AUTO, PULSE, SCANA, SCAND, SETTASK, SETTIMER, TASK, TIMEOUT, TIMER, TURNOFF, TURNON.

COMMUNICATIONS

The SAFE 8000 communicates in standard ASCII using two serial ports which are available in both RS-232 and RS-422 formats. All communication is fully interrupt driven for concurrent operation. Baud rates: 300, 600, 1200, 2400, 4800, 9600, 19200, 38400; parity: odd, even, none, force; stop bits: one, two; word length: seven, eight.

PID CONTROLLERS

Up to 64 PID controllers may be configured for real-time execution in the 'background'. Controllers operate independently of SAFE BASIC but may be dynamically tuned by SAFE BASIC, with all internal parameters such as the error and integral available to SAFE BASIC. Features include: cascade, analog or pulse duration outputs, square root extraction, anti-integral windup, output limiting, rate gain limiting, and automatic process value alarms. Operating modes include: ratio, ratio with bias, PID, P, PI, PD.

I/O SYSTEM

The SAFE 8000 I/O System consists of nineteen inch card cages, with up to eight cages in one system. Cages may be separated by up to 500 feet. Analog and digital modules may be mixed within a cage. Analog signals include: 10 mV, 100 mV, 1 V, 5 V, 10 V, 20 mA, 50 mA, thermocouples, and thermistors. Digital modules include: 5 V TTL, 12 V, 24 V, 48 V, 115 V, 220 V. Counters, frequency inputs and relays are also available.

ENCLOSURES

NEMA 4, NEMA 12 and general environment enclosures are available.

Note: Cover photo shows SAFE 8000 with personal computer for illustrative purposes.

SPECIFICATIONS

PROCESSOR

- 64K standard memory: 40K CMOS RAM, 24K ROM
- battery backup RAM with checksums
- 24 hour clock with calendar and day of week
- two RS-232/RS-422 serial ports, 300 BPS to 38400 BPS
- watchdog timer with auto restart
- extended BASIC programming language
- extensive self-diagnostics with menu
- 128 timers, 26 priority interrupts
- 64 real-time PID/RATIO controllers
- multitasking, error trapping and recovery
- 15 diagnostic and communication LEDs

I/O SYSTEM

- 128 12 bit analog, 2048 digital channels
- scan speeds to 64000 digital, 4000 analogs per second
- differential input analogs: 10mV, 100mV, 1V, 5V, 10V, 4-20mA, 10-50mA, thermocouple, thermister
- optically isolated digitals: 5V, 12V, 24V, 48V, 115V, 220V, relays, counters, frequency
- 19 inch, 16 slot I/O module cages
- expansion I/O cages remote to 500 feet
- low power, high noise rejection CMOS
- quick release front edge connectors

Note: detailed technical specifications are available. Ask for SAFE 8000 TECHNICAL BROCHURE.

Available from:

CONTROL MICROSYSTEMS INC.

6390 Notre Dame Street West
Montreal, Quebec, Canada
H4C 1V4
(514) 933-1136